THE CRYSTAL OSCILLATOR CHARACTERIZATION FACILITY AT THE AEROSPACE CORPORATION

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Abstract

At the present time, there is a need by the military for small, low-power, fast-warmup, and low g-sensitivity crystal oscillators for use in GPS receivers and transmitters in handheld survival radios and smart munitions. These units require a stable frequency source (crystal oscillators or small rubidium atomic clocks) for their operation. A variety of crystal oscillators are now on the market, and there is a need to evaluate the latest technology so that performance can be compared and evaluated. Insight into the characteristics of the various classes of crystal oscillators used by the contractors enables The Aerospace Corporation to identify the performance risks early in program development, which helps avoid schedule delays and later cost impacts. This paper describes a modernized clock-oscillator measurement facility that has been established at Aerospace to characterize these frequency sources in support of the military programs.

MEASUREMENT SYSTEM

In our frequency stability measurement system, we used the heterodyne single-mixer method **[1]** to measure the frequency fluctuations of the frequency source under test, as shown in Figure 1. The signal from the oscillator to be tested is mixed with a reference oscillator of almost the same frequency as the oscillator under test. This is done so that one is left with a lower average frequency (beat frequency) for analysis without reducing the phase or frequency fluctuations themselves. In our measurement system, we have improved the measurement capability by using more up-to-date hardware and software, as will be described in our paper.

Figure 2 shows the frequency stability measurement system. The system consists of the 5 and 10 MHz reference signals that are obtained from a HP5071A cesium or a high-stability Oscilloquartz #8600 oven-controlled crystal oscillator (OCXO) frequency sources. The cesium frequency standard is measured daily by a service supplied by the National Institute of Standards and Technology (NIST) to ensure that it meets the performance requirements. Figure 3 is a block diagram of our frequency stability measurement system. The measurement system consists of high-resolution time interval analyzers, mixers, frequency synthesizer, isolation amplifiers, and a PC that controls the instruments and processes the data.

The high-resolution time-interval analyzer is manufactured by Guide Technology, Inc. The GT 654 board can make 12-digit time-interval measurements on each of its two channels simultaneously, with measurement rates that are thousands of times faster than counters, zero dead-time capability, and single-shot resolution at 75 ps. Two of these boards are in the PC. The boards measure the time period of the beat frequency out of the mixers. The input frequency of our boards is DC–400 MHz (2.0 GHz input channels optional), and we have measured beat periods from 0.01 sec to 10 sec in our measurement system.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **The Crystal Oscillator Characterization Facility at the Aerospace Corporation**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The Aerospace Corporation,El Segundo,CA,90245**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001507. 34th Annual Precise Time and Time Interval (PTTI) Planning Meeting, 3-5 December 2002, Reston, VA

14. ABSTRACT
At the present time, there is a need by the military for small, low-power, fast-warmup, and low g-sensitivity crystal oscillators for use in GPS receivers and transmitters in handheld survival radios and smart munitions. These units require a stable frequency source (crystal oscillators or small rubidium atomic clocks) for their operation. A variety of crystal oscillators are now on the market, and there is a need to evaluate the latest technology so that performance can be compared and evaluated. Insight into the characteristics of the various classes of crystal oscillators used by the contractors enables The Aerospace Corporation to identify the performance risks early in program development, which helps avoid schedule delays and later cost impacts. This paper describes a modernized clock-oscillator measurement facility that has been established at Aerospace to characterize these frequency sources in support of the military programs.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**12**	

Figure 4 is a picture of our six-channel mixer system. Each channel consists of a mini-circuits mixer #ZAY-3, a low-pass filter, an amplifier, and a strobed threshold detector. Figure 5 is a schematic of our low-pass filter and amplifier. For the low-pass filter, we used an LT-1028 low-noise operational amplifier to minimize the noise and pass only the desired beat frequency (usually 10 Hz). The low-pass output signal is then fed into an OP-5 operational amplifier output buffer. Figure 6 shows the frequency response of the low-pass filter and amplifier. The beat frequency signal then is input to a strobed threshold detector, as shown in Figure 7. The purpose of the threshold detector is to square up the sinusoidal beat frequency and prevent false triggering by the electronics to follow. This is accomplished by creating a dead zone in time after each crossing in which the threshold detector is disabled. The output of the threshold detector is then fed into the time-interval analyzer for measurement of its beat period. The Programmed Test Sources, Inc. PTS model #250M6NIGSX-51 low-noise frequency synthesizer is used to offset the frequency reference to obtain the desired beat frequency. In our previous system, we used a Fluke 6160B frequency synthesizer, since the Fluke 6160B frequency synthesizer had the lowest noise contribution of all the frequency synthesizers on the market at that time. The reason for having the low-noise frequency synthesizer is the synthesizer noise contributions to the system noise-floor. Unfortunately, Fluke has discontinued manufacturing and maintaining this synthesizer. Therefore, we looked at the new synthesizers on the market and found that the PTS synthesizer was the closest to the Fluke 6160B frequency synthesizer in terms of noise floor.

In our measurement system, we currently use Erbtec isolation amplifiers to isolate the signals between the DUTs, the references, and mixers. This eliminates reflections due to mismatch of impedance levels. These isolation amplifiers have a frequency range of 1 to 100 MHz and a 100 dB isolation capability. At this time, the Erbtec isolation amplifiers are no longer available, but there are other manufacturers that make similar amplifiers. While the Erbtec devices are excellent isolation amplifiers, ultimately we will replace them.

We measured our system noise floor by using the frequency reference signal (HP5071A cesium) that was also input into the device under test (DUT) port. Figure 8 shows the system noise floor and the HP5071A cesium's performance. At a sampling period of 1 second, the system noise floor Allan deviation is 2.7×10^{-13}. We also note that even if the system noise floor is better than our reference source (HP5071A), we cannot measure any DUT that is better than the frequency reference source used.

Guide Technology, Inc. provided a limited set of LabVIEW drivers for use with the GT654 time interval analyzer, as well as a full set of drivers written in the C programming language. Using dynamic link libraries, we accessed C drivers not supplied with the LabVIEW driver set. In LabVIEW we were then able to access all the required board functions with a graphical user interface. In our measurement system, we currently have two GT654 boards; each board has two channels with 2 MB of RAM, allowing us to measure four oscillators simultaneously. Figure 9 shows the LabVIEW control window of our four channels, with each window displaying in real time the fractional frequency fluctuation for 100 samples.

To process phase data from each channel of the GT654 board, we use Hamilton Technical Services' Stable-32 software. This program does the analysis of frequency stability. The software includes all the functions necessary to manipulate, analyze, and plot time and frequency stability data.

Figure 10 shows a typical Allan deviation plot of a frequency standard, in this case a microcomputer-controlled crystal oscillator (MCXO). To characterize frequency standards over different temperature environments and profiles, we set up an automated temperature chamber, as shown in Figure 11. We used a Tenney JR temperature chamber that can range in temperature from –75°C to +200°C, ±0.3 degrees. The chamber uses a Watlow 942 microprocessor-based time and temperature profile controller, which interfaces with our PC over an RS232 interface. Custom drivers for the Watlow controller were written in the LabVIEW software so that we can program the chamber temperature profile, as shown in Figure 12.

The chamber has its own temperature sensor (RTD), but to monitor the actual temperature of the device under test, we use a Stanford Research Systems, Inc. 16-channel thermocouple monitor model SR630 with a 0.1°C resolution. This monitor is also used to measure the actual current drawn by the device under test, by using a 1-ohm precision resistor in the power line of the device under test. The monitor is also linked to the LabVIEW software by means of a custom driver. Figure 13 shows the block diagram of the setup.

Figure 14 shows a typical thermal data run on an oscillator. We have also developed a single sideband phase noise measurement system using the HP E5500 phase noise hardware with several Wenzel, Inc. low-phase noise reference oscillators. In addition, we have a Timing Solutions Corp. TSC 5110 time-interval analyzer for portable field use to measure frequency stability of oscillators that cannot be brought to our facility.

CONCLUSIONS

This paper has presented a description of the hardware and software of our crystal oscillator characterization facility at The Aerospace Corporation. We designed this system to be simple to use, and to provide a fast turnaround for characterization or verification of manufacturer data of any crystal oscillator. This facility is being used to support many military programs by assisting manufacturers in characterizing the oscillators for these programs.

ACKNOWLEDGMENTS

The authors are grateful to Gary Fisher for building the mixer box.

REFERENCES

[1] D. A. Howe, D. W. Allan, and J. A. Barnes, 1981, *"Properties of Signal Sources and Measurement Methods,"* in Proceedings of the 35th Annual Symposium on Frequency Control, 27-29 May 1981, Philadelphia, Pennsylvania, USA (IEEE Publication AD-A110870), pp. A1–A47.

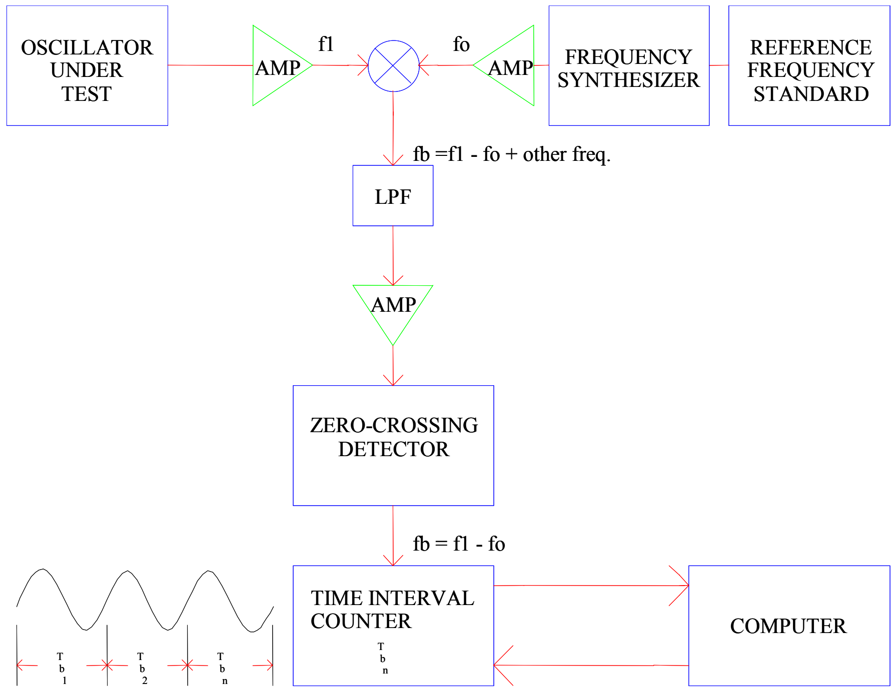

Figure 1. Block Diagram of a Single Mixer Heterodyne Measurement Technique.

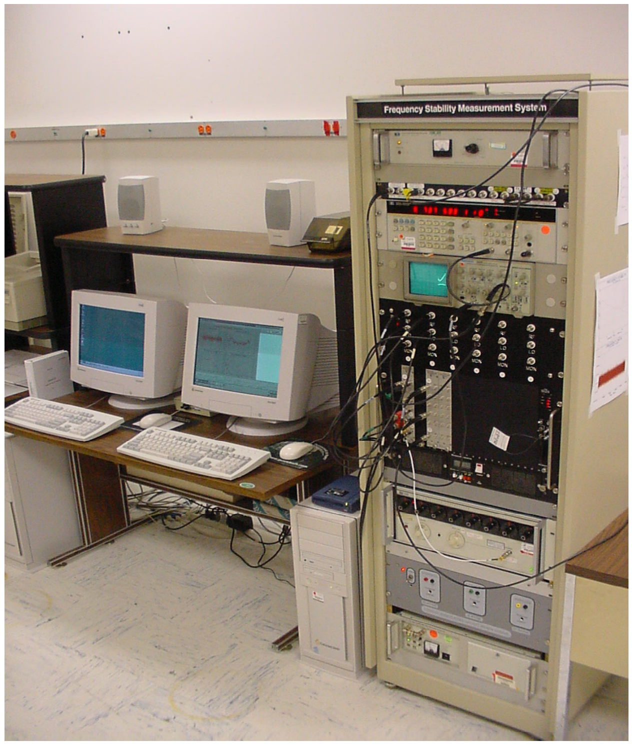

Figure 2. Frequency Stability Measurement System.

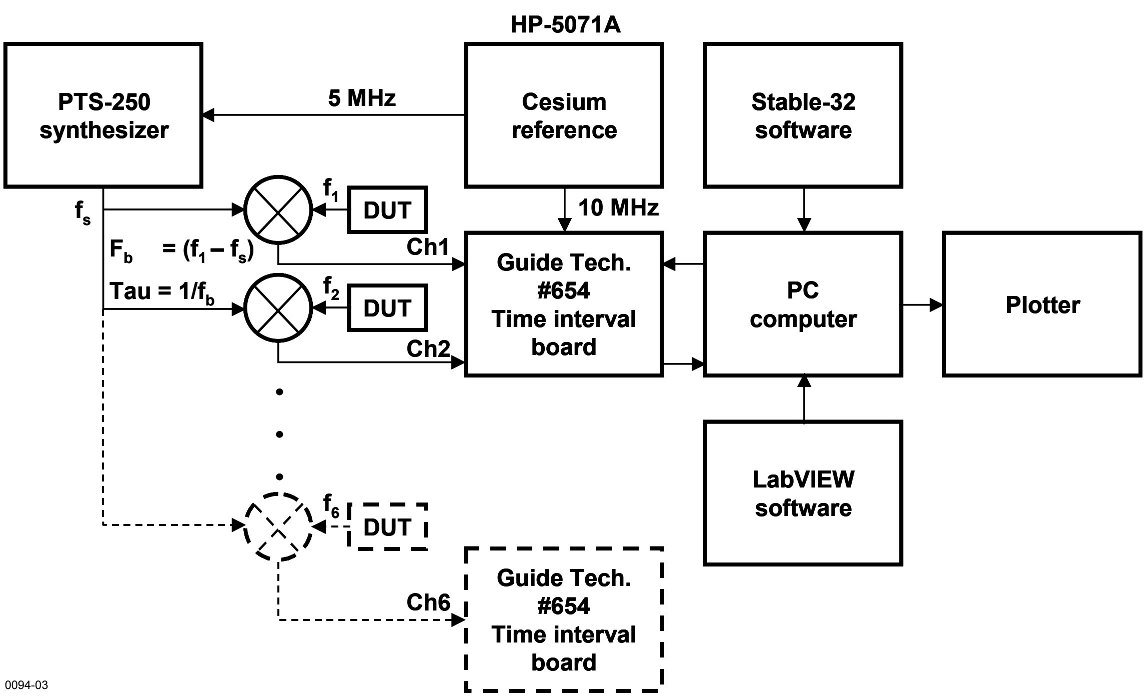

Figure 3. Block Diagram of the Multichannel Frequency Stability Measurement System.

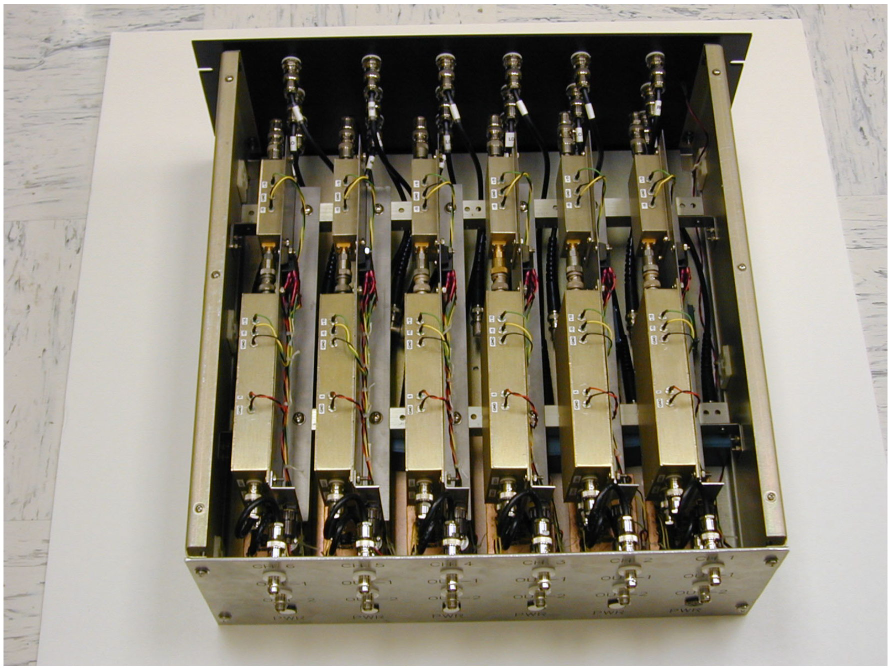

Figure 4. Multichannel Single Mixer System.

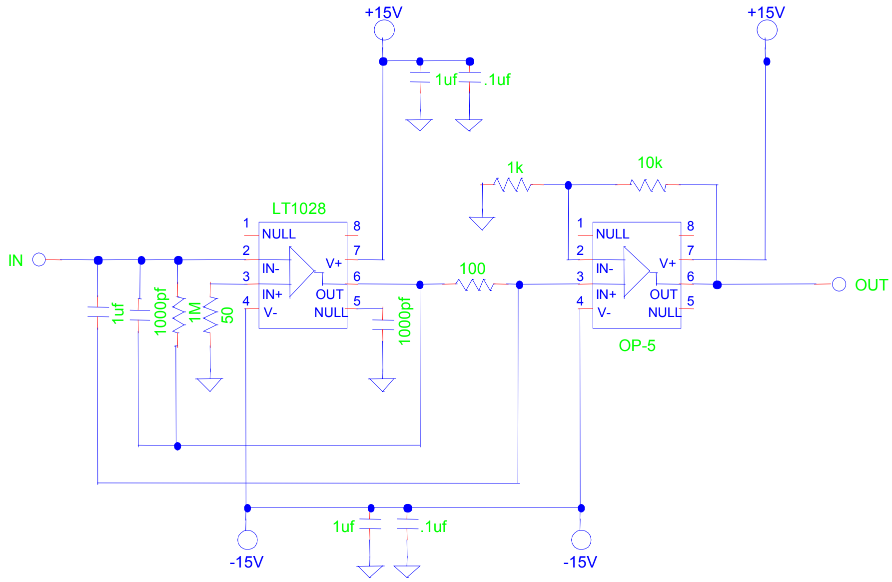

Figure 5. Circuit Diagram of the Low-Pass Filter and Amplifier.

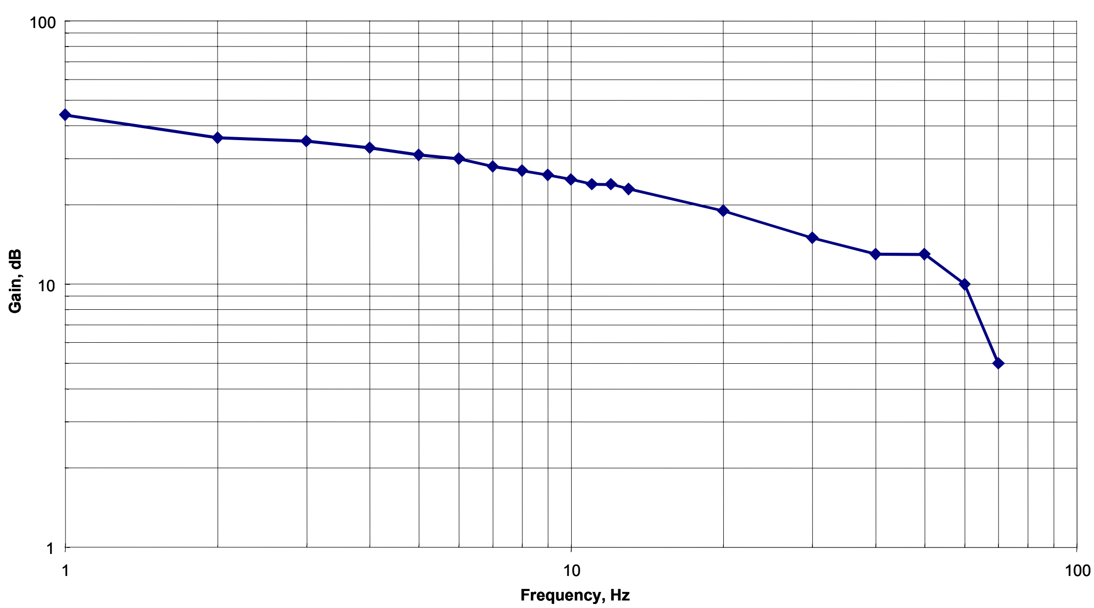

Figure 6. Plot of the Frequency Response of the Low-Pass Filter and Amplifier.

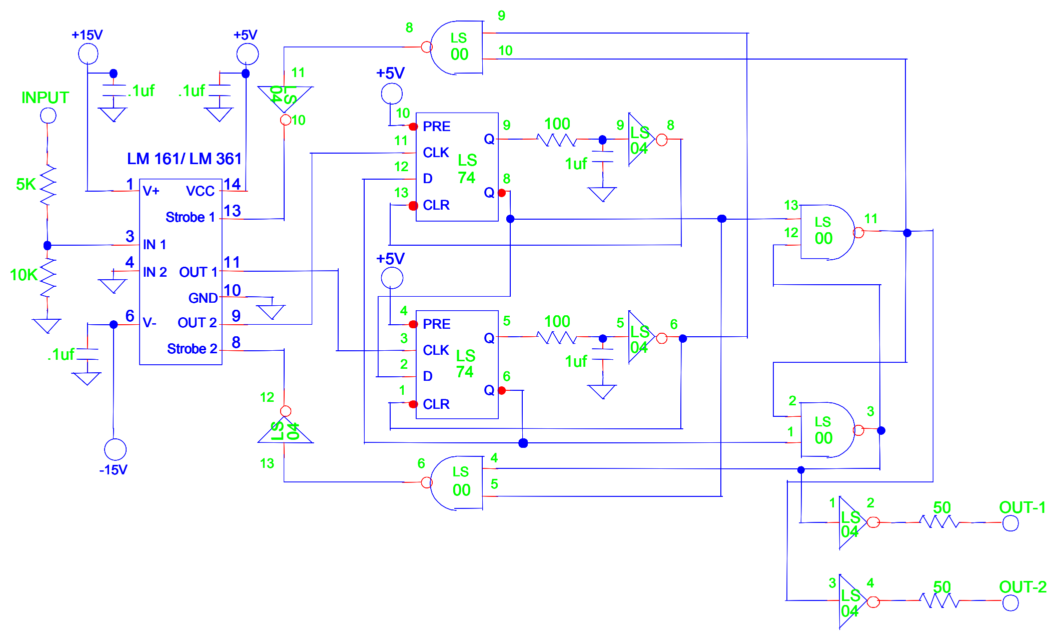

Figure 7. Schematic Diagram of the Zero-Crossing Threshold Detector.

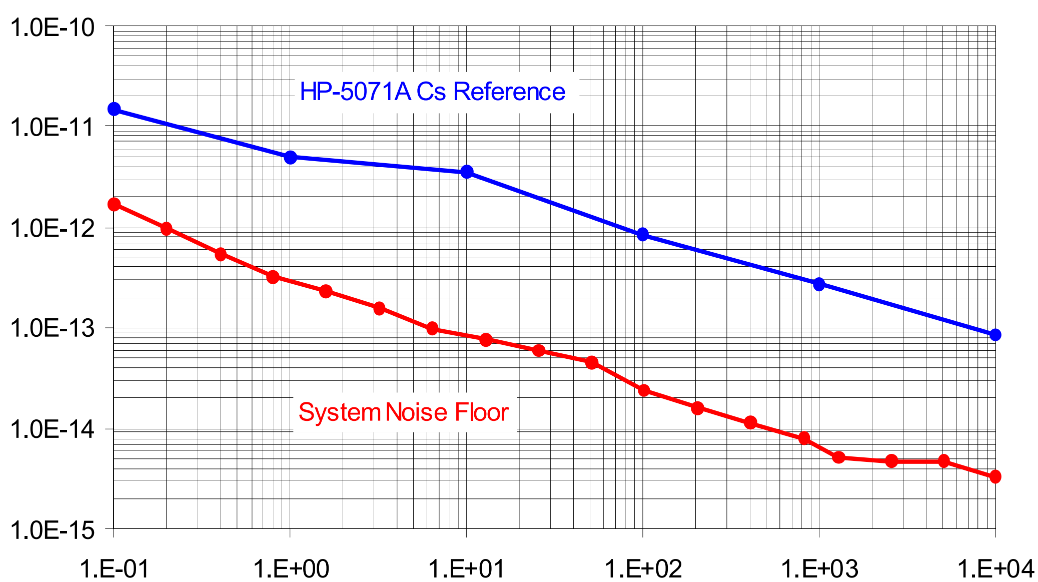

Figure 8. The Measured Allan Deviation of the Cesium Frequency Standard Reference and the Frequency Stability Measurement System Noise Floor.

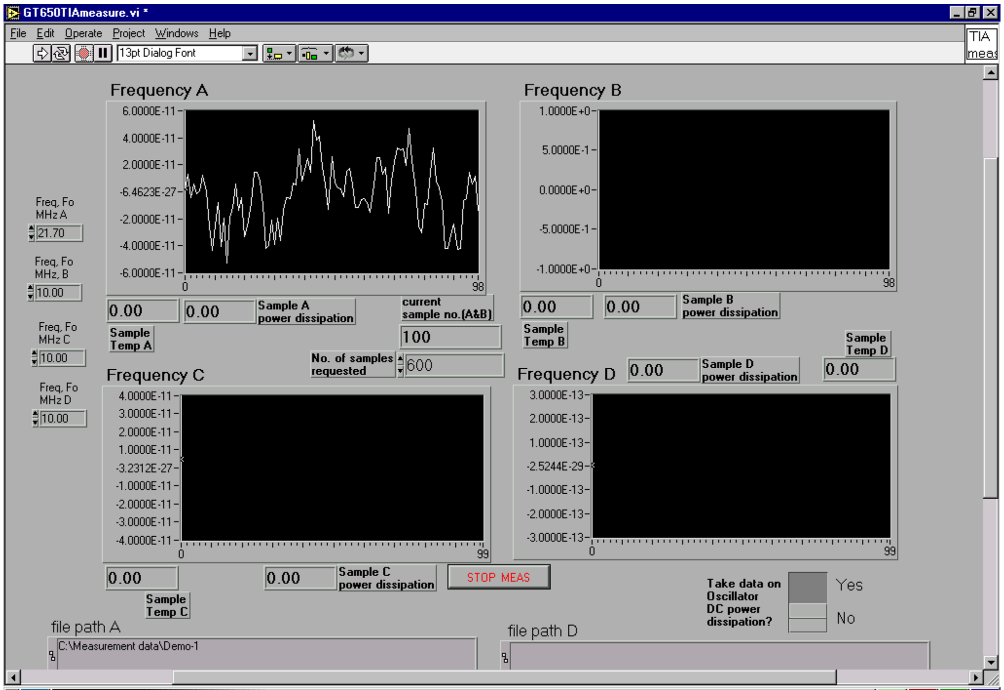

Figure 9. Real-time Fractional Frequency Plot of the Multichannel Frequency Stability Measurement System.

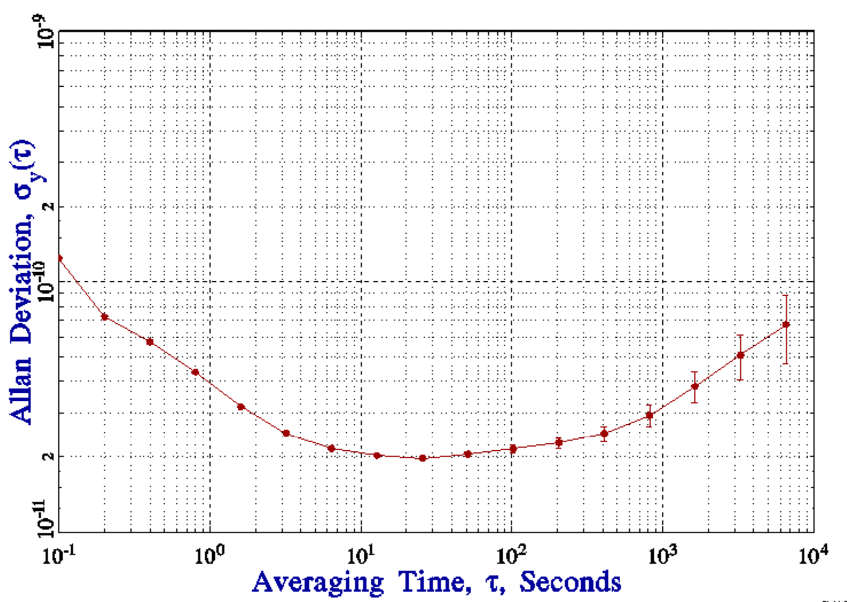

Figure 10. Plot of the Allan Deviation of a Microcomputer-Controlled Crystal Oscillator.

Figure 11. The Temperature Chamber.

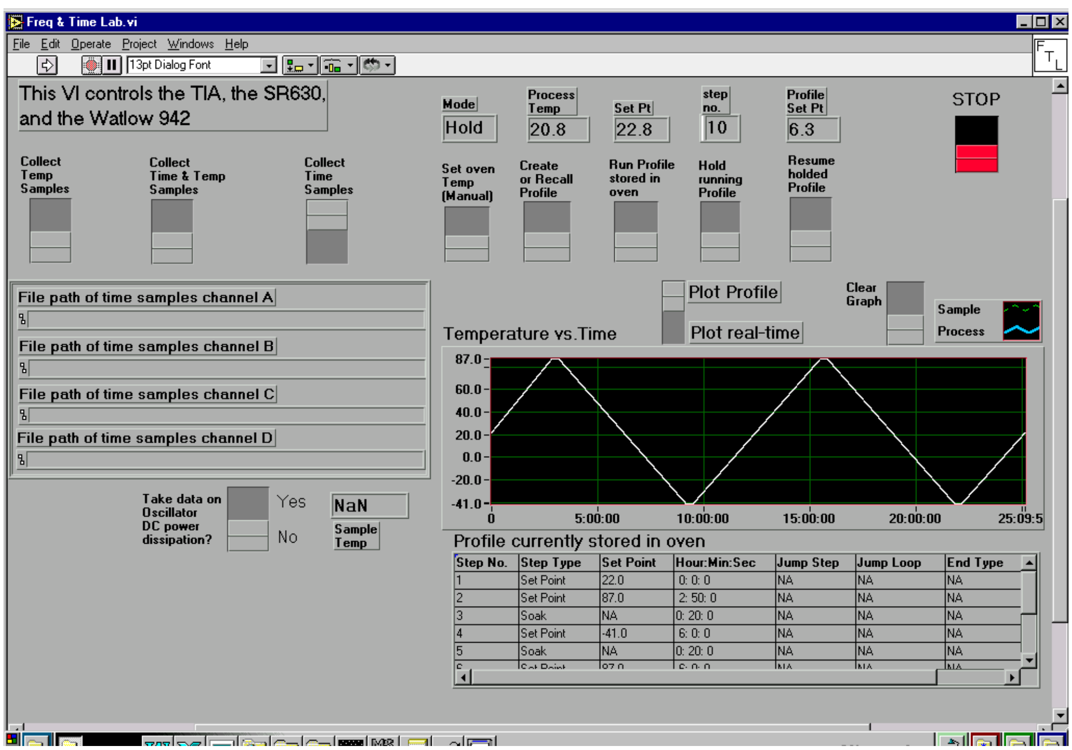

Figure 12. Computer-Controlled Temperature Chamber Temperature Profile Program.

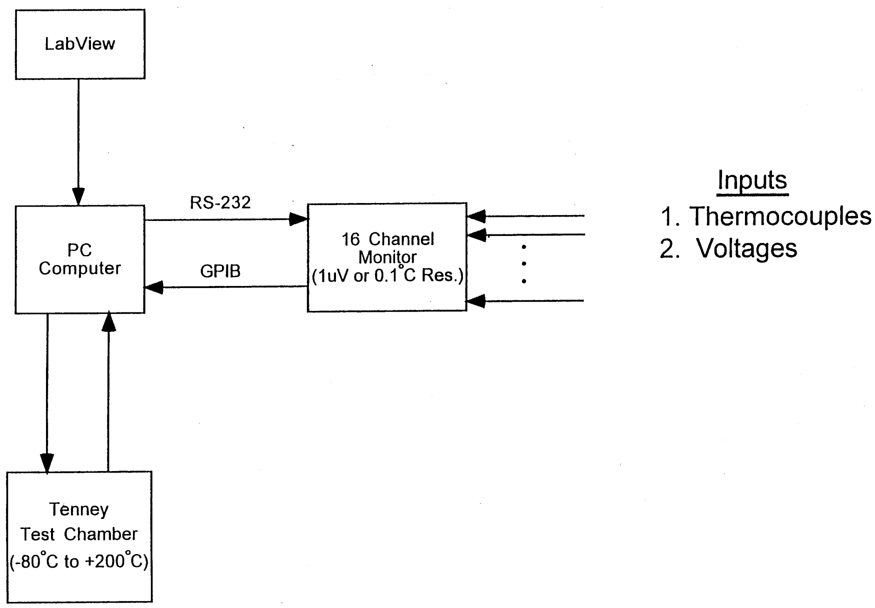

Figure 13. Block Diagram of the Computer-Controlled Temperature Chamber System.

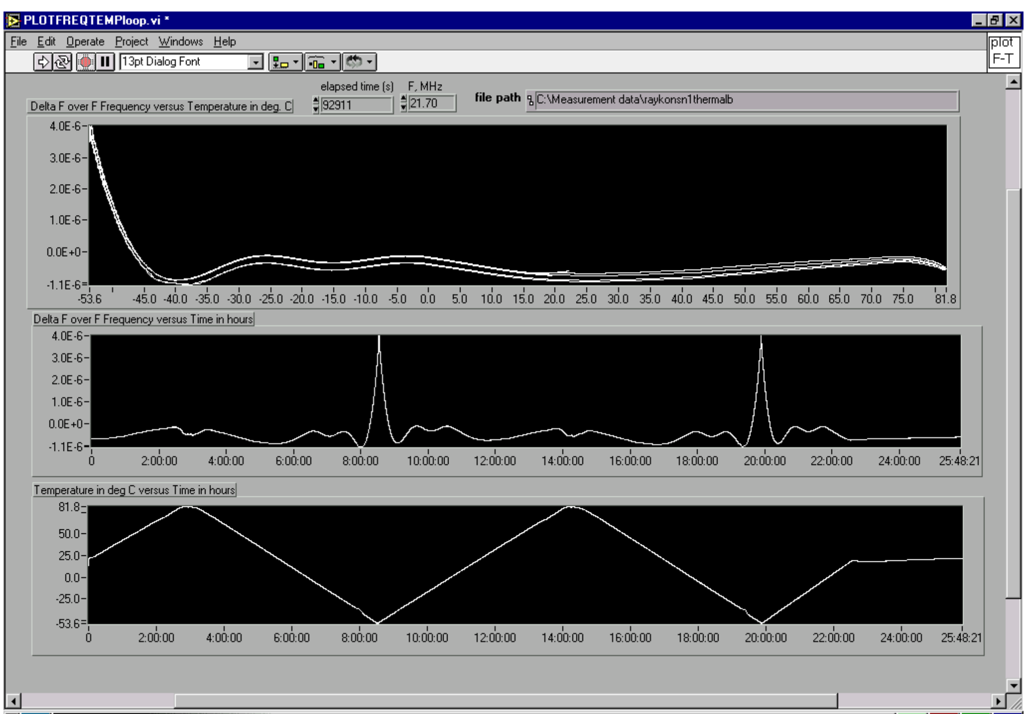

Figure 14. Plot of a Temperature-Compensated Crystal Oscillator Fractional Frequency Response Due to Temperature Change.